

An Efficient Error Resilience Scheme based on Wyner-Ziv Coding for Region-of-Interest Protection of Wavelet based Video Transmission

ZHUO XUE¹, K.K. LOO¹, J. COSMAS¹, P.Y. YIP²

¹ School of Engineering and Design, Brunel University

² School of Computer Science, University of Hertfordshire

UNITED KINGDOM

{Zhuo.Xue, Jonathan.Loo, John Cosmas}@brunel.ac.uk, p.y.a.yip@herts.ac.uk

Abstract: - In this paper, we propose a bandwidth efficient error resilience scheme for wavelet based video transmission over wireless channel by introducing an additional Wyner-Ziv (WZ) stream to protect region of interest (ROI) in a frame. In the proposed architecture, the main video stream is compressed by a generic wavelet domain coding structure and passed through the error prone channel without any protection. Meanwhile, the predefined ROI area related wavelet coefficients obtained after an integer wavelet transform will be specially protected by WZ codec in an additional channel during transmission. At the decoder side, the error-prone ROI related wavelet coefficients will be used as side information to help decoding the WZ stream. Different size of WZ bit streams can be applied in order to meet different bandwidth condition and different requirement of end users. The simulation results clearly revealed that the proposed scheme has distinct advantages in saving bandwidth comparing with fully applied FEC algorithm to whole video stream and in the meantime offer the robust transmission over error prone channel for certain video applications.

Key-Words: - Distributed Video Coding, Wyner-Ziv, Wavelet, ROI, Integer Wavelet Transform.

1 Introduction

With the development of communication network and multimedia technology, various types of multimedia service become available and more and more multimedia technology are delivered for multimedia information transmission over various types of channel. The diversities of channel conditions, device/terminal capabilities and the end user requirements make it necessary to provide different services for different purposes. In most popular video coding standard, video source is compressed to reduce the spatial and temporal redundancy by using motion estimation and compensation and DCT transform etc. It is only until 1993 after Jusséf Shapiro [1] firstly introduced embedded zero tree wavelet (EZW) to encode wavelet coefficients, the Discrete Wavelet Transform (DWT) begin to be widely used in image and video compression to exploit the spatial redundancy. Comparing to the traditional DCT transform, the DWT has distinct advantages in reducing the block artifacts especially at the low bit rate and inherited scalability characteristic. With these advantages, the wavelet based video transmission using generic predictive coding structure has been proposed in many ways to apply in different areas [2-11]. However, the algorithm has to consider the channel error occurrence

especially the zero tree coding used in EZW or SPIHT [12] make wavelet based video compression very sensitive to error prone. Even a small error of wavelet coefficients in transmission could be propagated to influence whole image reconstruction quality. The video bitstream is sensitive to the bit error or the packet loss that occurs in the channel. To deliver the bitstream over an error-prone channel, the video has to be coded with error resilience to endure the channel error and provide the error concealment scheme. In recent years, to design a robust video transmission techniques over heterogeneous and unreliable channels become the new challenge for the wavelet based video transmission and various works have been proposed in [9-13].

It is undoubted that the bandwidth will be timed if a FEC algorithm applied to protect whole video stream. However, in many practical application areas such as medical image, video surveillance system etc., there exists within a frame that one or more regions of greater interest than others. Therefore it is possible to give higher priority to those ROI areas than other areas during transmission. Technically speaking, we can purposely protect the wavelet coefficients related to ROI area other than whole frame by adding error coding scheme. Since the number of related wavelet

coefficients is much less than the wavelet coefficients of whole frame, only a small bitstream will be generated additionally, which avoids huge bandwidth cost but can provide significant improvement in ROI area, and eventually result in gain in term of compression and bandwidth efficiency. The similar idea can also be found in [14-21].

The Wyner-Ziv coding from distributed lossy source coding theory has been recently adopted as error resilience method in video transmission. In this paper, we apply this algorithm to wavelet video transmission. The ROI related wavelet coefficients will be sent to WZ codec for protection. The decoder will update the ROI related wavelet coefficients by using decoded coefficients from WZ stream and a better ROI area can be reconstructed. The end users can evaluate the decoding quality and request different size of WZ stream based on the available bandwidth to get various output quality, by which the tradeoff between the bandwidth utilization and error resilience is realized.

2 Related Work

2.1 Region of Interest (ROI)

ROI feature is supported in JPEG 2000 which adopted DWT to perform special compression, where ROI image can be coded with better quality than background. In general, two main kinds of methods are defined in [22 23 24], which are the general scaling based method and the maximum shift method. The principles of two methods are similar, in which after wavelet transform, the resulting coefficients not related to ROI will be scale down so that the ROI-associated bits are placed in the higher bit plane. During embedded encoding process, the bits in higher bit plane will be sent earlier than those bits in lower bit plane. To carry out this process, a ROI mask will be generated to indicate all the wavelet coefficients related to ROI. In this paper, the ROI mask generation method from [23] to identify the coefficients has been adopted. However, we won't scale the ROI related coefficients as in JPEG 2000, but only use ROI mask to indicate the position of ROI related coefficients, which will be sent to WZ codec for transmission.

2.2 Wyner-Ziv Coding

WZ coding is referred to lossy compression with side information at decoder. Details of WZ coding and application of distributed video coding can be

referred to the literatures [25 26 27]. In [28], multiple embedded Wyner-Ziv video descriptions is first used in systematic lossy error protection for video waveform. In [29 30 31], by using the redundant slices and flexible macroblock ordering, the "SLEP" scheme is proposed for H.264/AVC, with which an additional WZ bitstream is transmitted to realize error resilience. In this paper, additional WZ bitstream will be used to protect ROI related wavelet coefficients. The related wavelet coefficients are quantized and encoded by turbo codec. The generated systematic bits will be discarded and only the parity bits will be saved into buffer and compose the relevant bits stream to sent based on available bandwidth. At the decoder side, the reconstructed ROI related wavelet coefficients from wavelet video codec will be used as side information to help turbo code to perform decoding. The main advantage of using WZ coding is that bandwidth can be efficiently used by WZ stream. The required bandwidth is dynamically controlled by degree of error of side information, which is ROI related DWT coefficients passed through the error channel without any protection in normal wavelet video stream and end users. If there are not too many errors happened in the side information, then it can successfully decode the WZ stream with very small amount of parity bits. In contrast, if the side information has been corrupted badly during transmission, the bandwidth utilization will be increased by sending more parity bits for decoding and eventually recover the error of side information successfully.

2.3 ROI Mask Generation

The ROI mask is a bit plane indicating a set of wavelet coefficients whose exact transmission is sufficient for the receiver in order to reconstruct the desired region perfectly. The details of ROI mask derivation should refer to [23]. In this paper, the mask is a matrix which was initialized to zero with same size of the frame. The mask is derived following the same steps as the forward transform by tracing the inverse transform backwards. The position of all the coefficients used to reconstruct the pixel in ROI area will be marked in mask. However, it should be mentioned here that in order to get the complete reversible transform, the integer wavelet transform based on lifting scheme is used here. In this paper, the CDF 9/7 wavelet (where 9 and 7 denote the number of filter taps) which is selected as one of the wavelets for the JPEG2000 image format is considered.

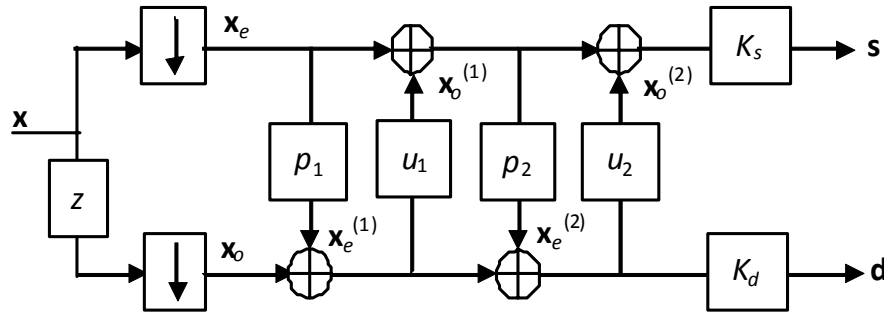


Fig. 1 Wavelet transform based on lifting scheme

The lifting scheme analysis is described with a sequence of “predict” and “update” filters. Consider a signal $\mathbf{X} = (x_k)_{k \in \mathbf{Z}}$ with $x_k \in \mathbf{R}$. We first split it in two disjoint sets: the even indexed samples $\mathbf{X}_e = (x_{2k})_{k \in \mathbf{Z}}$ and the odd indexed samples $\mathbf{X}_o = (x_{2k+1})_{k \in \mathbf{Z}}$. Typically these two sets are closely correlated. Let $p_i(\mathbf{X}_e)$ (where $i=1,2$ in CDF9/7 wavelet) denote the predict operation on \mathbf{X}_e , $u_i(\mathbf{x}_o)$ (where $i=1,2$ in CDF9/7 wavelet) denote the update operation on \mathbf{X}_o . The lifting scheme of CDF9/7 is shown in Fig. 1. In Fig. 1, $p_1, p_2 \dots$ denote predict filters, and $u_1, u_2 \dots$ denote update filters, $K_s = \zeta$ and $K_d = 1/\zeta$. The parameters for the filters in the format of Z transform are as follows,

$$p_1(z) = \alpha(z+1), \alpha = -1.586\ 134\ 342\ 060 \quad (1)$$

$$u_1(z) = \beta(1+z^{-1}), \beta = -0.052\ 980\ 118\ 573 \quad (2)$$

$$p_2(z) = \gamma(z+1), \gamma = 0.882\ 911\ 075\ 531 \quad (3)$$

$$u_2(z) = \delta(1+z^{-1}), \delta = 1.149\ 604\ 398\ 860 \quad (4)$$

To obtain the detail information \mathbf{d} and smoothed values \mathbf{s} , we have

$$\mathbf{s} = \mathbf{x}_e + \mathbf{x}_o^{(1)} + \mathbf{x}_o^{(2)} \quad (5)$$

$$\mathbf{d} = \mathbf{x}_o + \mathbf{x}_e^{(1)} + \mathbf{x}_e^{(2)} \quad (6)$$

where

$$\mathbf{x}_e^{(1)} = p_1(\mathbf{x}_e) \quad (7)$$

$$\mathbf{x}_o^{(1)} = u_1(\mathbf{x}_o + \mathbf{x}_e^{(1)}) \quad (8)$$

$$\mathbf{x}_e^{(2)} = p_2(\mathbf{x}_e + \mathbf{x}_o^{(1)}) \quad (9)$$

$$\mathbf{x}_o^{(2)} = u_2(\mathbf{x}_o + \mathbf{x}_e^{(1)} + \mathbf{x}_e^{(2)}) \quad (10)$$

After the “predict” and “update” filtering steps, \mathbf{X}_e is multiplied by K_s and \mathbf{X}_o is multiplied by K_d . For the inverse transform, undo the K_s and K_d scale factors, change additions to subtractions, and perform the filtering steps in the reverse order. During the transform, at each decomposition level, the mask will indicate which coefficients are needed exactly at this level so that the inverse transform will reproduce the ROI related coefficients in previous level exactly. The ROI mask matrix is grown slowly following the forward transform until whole transform is finished. According to this mask, the ROI related coefficients will be picked out and sent to WZ codec for transmission. A typical example definition of ROI mask is show below:

$$M(x,y) = \begin{cases} 1, & \text{the coefficient located at } (x,y) \text{ is} \\ & \text{related to ROI and therefore need to} \\ & \text{be picked out and protected} \\ 0, & \text{the coefficient located at } (x,y) \\ & \text{is not related to ROI therefore can} \\ & \text{be neglected} \end{cases}$$

3 Proposed architecture

Fig. 2 illustrated the concept of the proposed error resilience scheme for wavelet video transmission based on Wyner-Ziv coding. The input signal is compressed and sent by normal wavelet based video transmission on an error prone channel without any protection. The wavelet based video transmission adopted generic video prediction structure, which employs DWT, motion estimation and compensation, and entropy coding to realize spatial,

temporal and data compression. The ROI area is manually defined before DWT decomposition. The ROI mask which indicates the corresponding coefficients in wavelet domain for reconstruct the ROI is generated after DWT decomposition. By using ROI mask, wavelet coefficients related to ROI will be progressively scanned and quantized. The generated bitstream is sent to WZ codec for coding.

Only the generated parity bits will be sent and the number of parity bits sent depends on the end user's requirement. It should be specially mentioned that only the ROI area of I frame will be protected, by which the corresponding ROI area in P or B frames can also be better reconstructed as well since I frame is used as reference frame to build P or B frame.

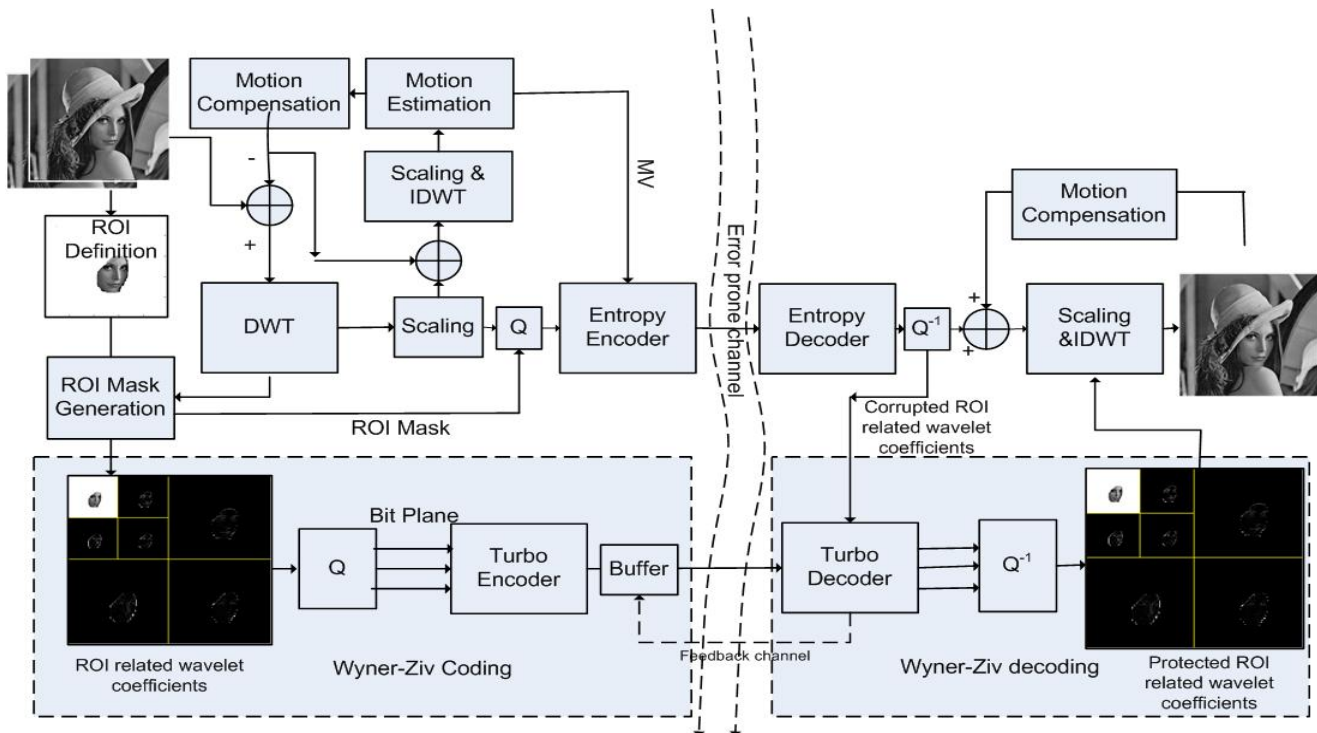


Fig. 2 Proposed WZ error resilience scheme for wavelet based video transmission

Note that the ROI mask still needs to be sent to decoder via normal channel in order to rebuild the side information. Each ROI related coefficient will be uniformly quantized and sent via bit plane. The turbo encoder used here worked with RCPT [31] to realize dynamic rate control of WZ stream. The generated parity bits are saved into buffer and wait for transmission, while all systematic bits are discarded. Based on the available bandwidth, the required code rate is decided and the puncturing will be performed. The parity bits after puncturing will be passed through the channel. At the turbo decoder, by using received ROI mask, the error corrupted wavelet coefficients of ROI region will be picked out and used as side information to help turbo decoder to perform decoding, in which the error-prone wavelet coefficients will be quantized by same levels as in encoder and play the role of channel corrupted systematic bits in decoding. After all bit planes are decoded, the whole symbol will be dequantized and all the ROI related wavelet

coefficients will be rebuilt, which later than replaced the error corrupted ROI coefficients in frame. IDWT is then performed and the whole picture is rebuilt subsequently. Moreover, the end user can evaluate the quality of output, if it cannot satisfy the requirement, the end user can request higher bit rate WZ stream via feedback channel. This kind of request make the scheme very flexible since the encoder will only need to send more parity bits from buffer other than to transmit all information and repeat the whole process.

4 Experimental Results

In this section, the performance of proposed error resilience scheme is demonstrated. We investigate the scenario of wavelet based video transmission over wireless link. Typically, the AWGN channel has been adopted as type of error-prone channel. Turbo code composed by two identical constituent convolutional encoder of rate 1/2 with constraint

length of 4 and with polynomial generator of (13,11) is adopted in this architecture. The puncturing period of RCPT is set to 8, which provided various code rates of (8/9, 8/10, 8/11,...1/3 etc). The wavelet transform filters used here are the CDF 9/7 filter set with lifting scheme to perform fast integer wavelet transform. The frame rate is set to 13fps, GOP size is 36 with structure of IBBPBBP.... Note that since proposed scheme only deal with I frame, therefore the frame rate actually sent into WZ codec is only 0.3fps. 256 levels Quantization is performed for ROI related coefficient to provide lossless quantization. Two CIF sequences "Foreman" and "Akiyo" have been tested during simulation. Moreover, to simplify the analysis, we manually defined ROI area in rectangular shape. The ROI shape can be arbitrary and generated automatically by several current available methods.

Fig. 3, 4 and 5 illustrated PSNR performance of 2 sequences under different channel conditions with different error protection schemes. We tested each sequence with different degree of protection, which are no protection, various WZ stream protections, and full protection (protect whole video stream by turbo code with rate 2/3) under the AWGN channel with channel SNR of 6 dB and 8 dB. As shown in the Fig. 3 and 4, the channel noise has corrupted the video stream seriously. Without any protection, the reconstructed video quality is very poor and very low

PSNR can be observed. It can be seen that with full protection of whole video stream, almost all errors have been corrected and therefore the gained PSNR is much higher than all other schemes as expected but the huge bandwidth cost cannot be avoided, with which another additional 147 kbps for Akiyo sequence and even 229 kbps for Foreman sequence have to be occupied. With WZ protection scheme, the additional WZ stream obviously enhances the system to certain extent. Higher is the WZ stream, namely more parity bits are sent, better the PSNR gain can be obtained. It should be noticed that the WZ stream only occupy a very little bandwidth, but the system gain is distinct. The 16 kbps WZ stream can improve PSNR up to 19 dB for Akiyo sequence and 12 dB for Foreman sequence with 25 kbps WZ stream. The 16 kbps and 25 kbps for two sequences are the highest bitstream that can almost decode the ROI related wavelet coefficients error free in the simulation, which also implies the higher bandwidth needed for the proposed scheme in the case of two sequences. In Fig. 5, the channel condition is better with SNR of 8 dB. Although same trend in performance can be found as in Fig. 2 and 3, we can see that with better channel condition, the WZ stream with lesser bandwidth is needed to decode a higher quality of output. Therefore the proposed scheme has certain flexibly in adapting the channel condition.

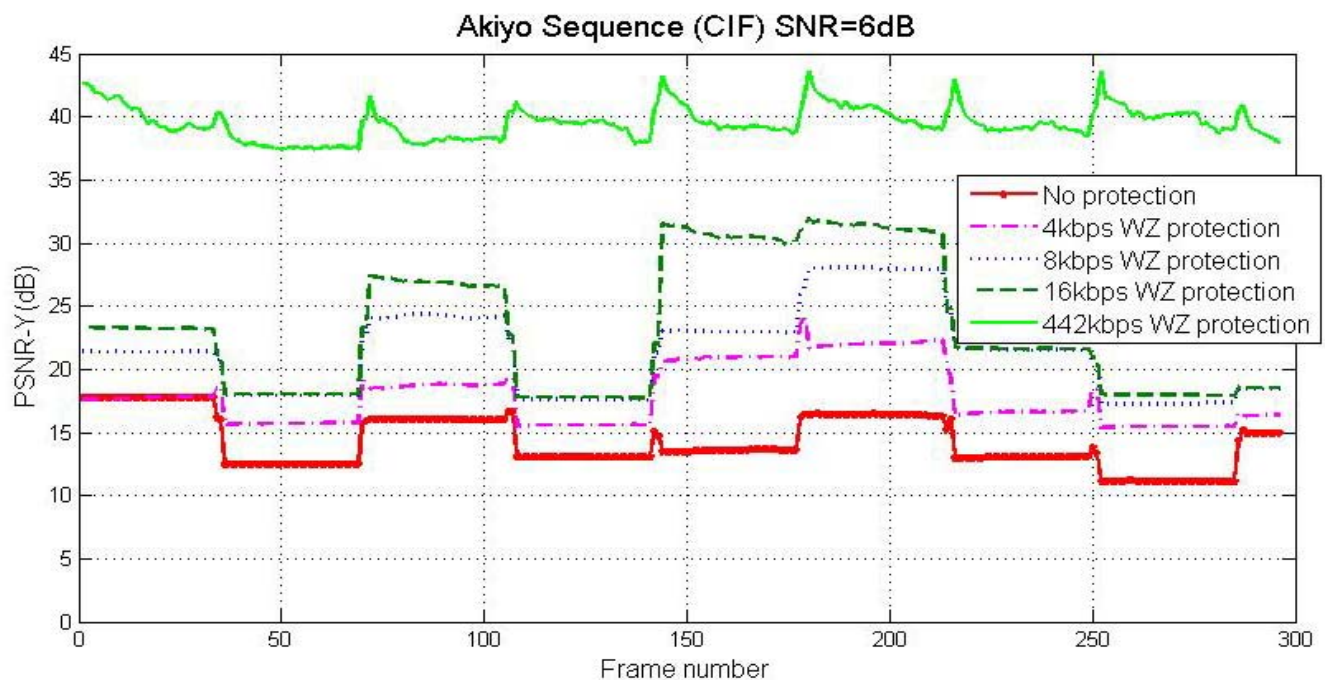


Fig. 3 PSNR performance of Akiyo sequence with different protection schemes

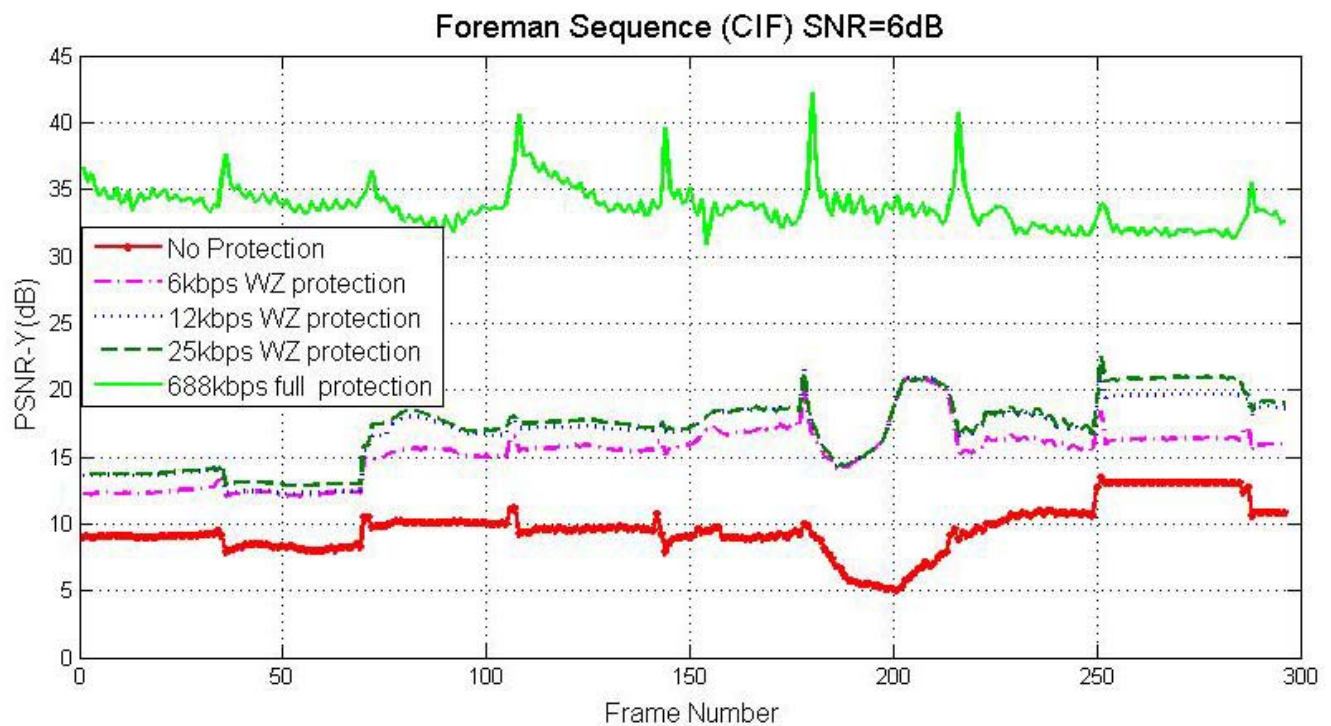


Fig. 4 PSNR performance of Foreman sequence with different protection schemes

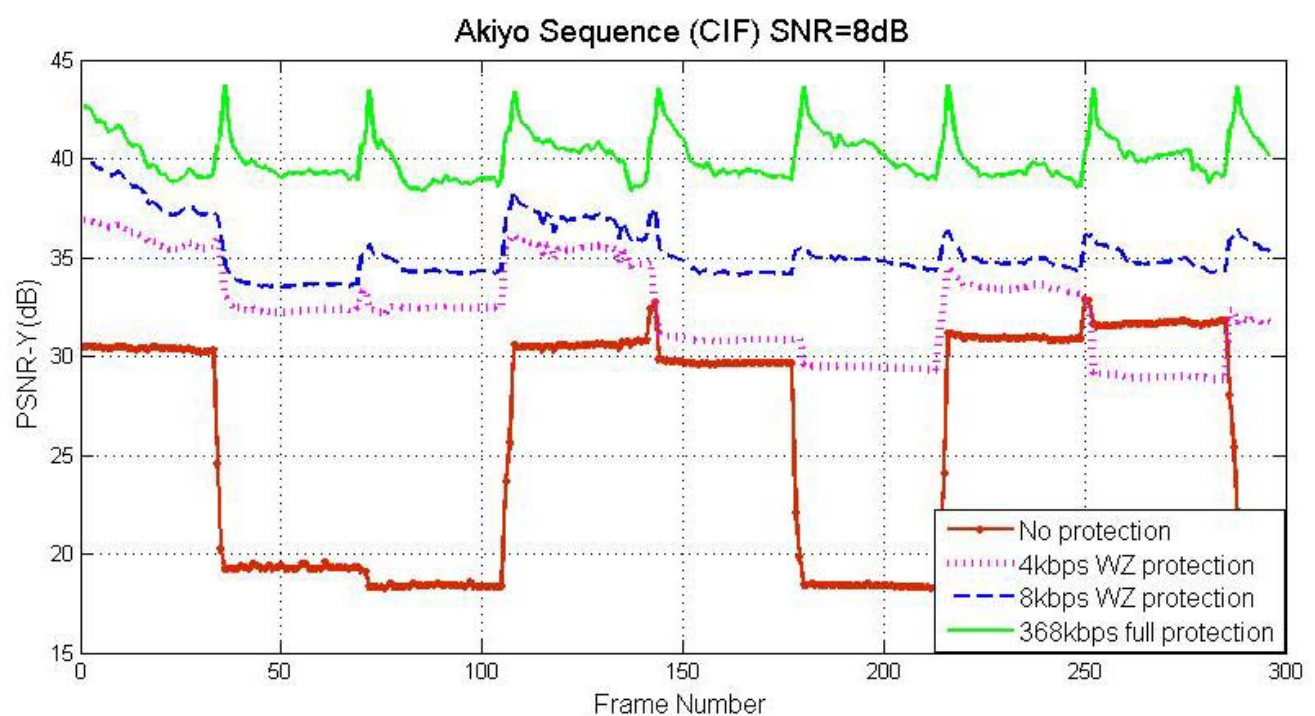


Fig. 5 PSNR performance of Akiyo sequence with different protection schemes

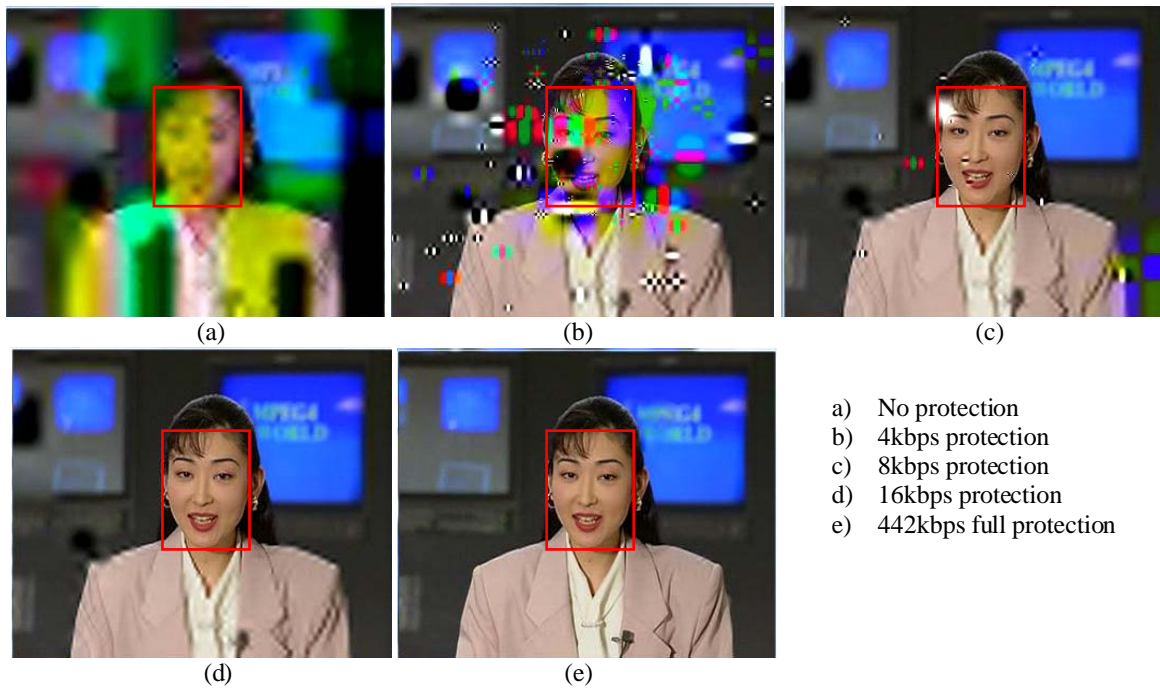


Fig. 6 Perceptual quality comparison of 73rd frame (I frame) of Akiyo with different protection schemes

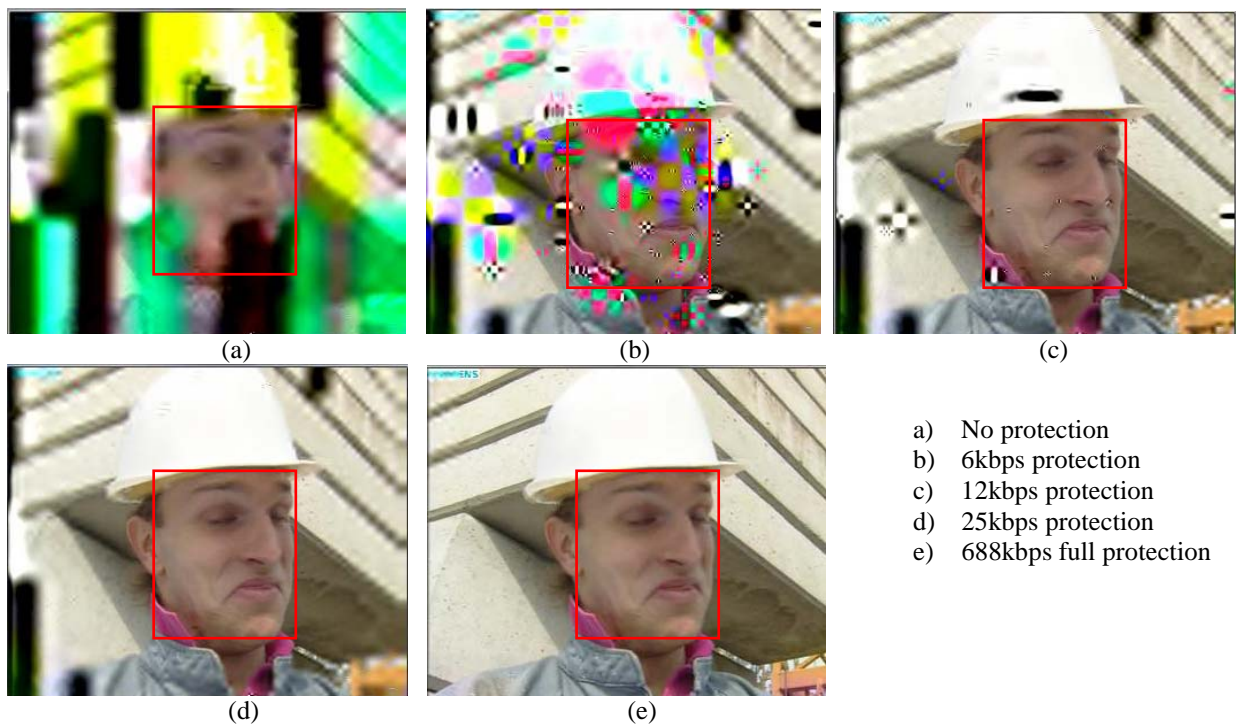


Fig. 7 Perceptual quality comparison of 73rd frame (I frame) of Foreman with different protection schemes

Most importantly, with ROI protection, the ROI area, which is considered more interesting and important area than background can be better reconstructed. Fig. 6 and 7 showed the perceptual quality comparison for one I frame of two sequences. The perceptual quality of the reconstructed image

without any protection is generally unacceptable to end user. However, with ROI protection, the steadily improved pictures can be observed with different degree of ROI protection. The perceptual quality especially in ROI area (circulated by red rectangular) has been much improved. In the case of

16 kbps protection for Akiyo and 25 kbps protection for Foreman, the reconstruction of ROI area is almost same as full protection scheme. Although there are still some temporal errors and decoding errors that can be spotted in the outside ROI, if we only concern about the quality of ROI area, then the perceptual quality of whole frame is much acceptable. For example, in the cloth area of Akiyo frame, although it can be found with blurring effect due to the temporal errors, the whole frame make almost no difference with full protection scheme to

the end-user if we mainly concentrate in the ROI area.

Moreover, with the increase in the accuracy of ROI related coefficients due to the protection, not only the ROI area is better reconstructed, but also other areas which would use ROI related DWT coefficients for reconstruction will also be improved. This effect can be clearly proved in Fig. 6 and 7 that some areas lying outside of ROI are also much improved.



Fig. 8 Perceptual quality comparison of 74th frame (B frame) and 76th frame (P frame) of Akiyo with different protection schemes for the 73rd frame (I frame)

Table 1. Bandwidth unitization comparison with channel SNR = 6 dB

	ROI size	NO protection compression bit rate	Fully protection bit rate	Additional bandwidth for full protection	Additional bandwidth for WZ stream	Bandwidth saved
Akiyo	142x154	295 kpbs	442 kbps (Code rate is 8/12)	147 kbps	4 kbps	97.3%
					8 kbps	94.6%
					16 kbps	89.2%
Foreman	96x144	459 kpbs	668 kbps (Code rate is 8/12)	209 kbps	6 kpbs	97.2%
					12 kpbs	94.3%
					25 kpbs	89.9%

Fig. 8 showed the reconstructed B and P frame for Akiyo sequences. As analyzed in the previous section, since the I frame is the basic reference frame to reconstruct the B and P frame, the general

enhancement in the quality of I frame therefore undoubtedly has positive effect to help generate the better B and P frame. In Fig. 8, the apparent improvement of B and P frame can be observed.

Moreover, the same increasing trend also can be observed as in Fig. 3, 4 and 5, in which the peak area in above figures represent the enhancement of I frame and the enhancement also has been propagated to the following B and P frames.

Table 1 shows the actual bandwidth utilization for each scheme illustrated in Fig. 3 and 4. It is obvious that the full protected scheme occupied times bandwidth of the original stream to maintain higher error correction ability. In the case of 6 dB channel, the full protection needs to occupy another additional nearly 50% bandwidth of original bandwidth without protection to provide the error resilience. The worse channel would require even higher bandwidth. However, with WZ stream, influenced by ROI size, WZ frame rate, quantization level and final decoding code rate, is little bandwidth usage comparing to two other methods. However, this little bandwidth usage can efficiently protect the ROI and provide the decent output video quality around ROI area. Most importantly, when compare to fully protected stream, the bandwidth usage of proposed scheme could save around 90% and provide satisfactory output quality in term of end users interest in the meantime.

5 Conclusion

In this paper, we propose a bandwidth efficient error resilience scheme based on WZ coding to give priority protection to ROI area for wavelet based video transmission on error prone channel. By introducing additional WZ coding with negligible complexity, the ROI related wavelet coefficients after DWT transform are marked by ROI mask and coded by WZ codec subsequently. The received ROI related wavelet coefficients from main video stream then are used to help decoding. Finally the decoded wavelet coefficients replace the corroded coefficients and the ROI area is protected and better reconstructed. With the proposed scheme, the wavelet based video system can be expected much more robust during transmission. Furthermore, in the proposed scheme, since the ROI related wavelet coefficients are finely protected and these coefficients also are used to reconstruct other wavelet coefficients in IDWT process, the rest regions also have been improved to certain extent and a general enhancement in the frame can be observed. Although the proposed scheme only protect the I frame in sequence, the following B and P frames are also correspondingly improved due to the increase in the pixel accuracy of I frame, which

is used as reference frame to build B and P frame. A feedback channel is provided to end user to choose different WZ bitstream in order to get different output quality based on the available bandwidth. This has given much flexibility to the proposed scheme to adapt various requirement and bandwidth condition. In comparison with the FEC algorithm fully applied to whole wavelet coefficients, the introduction of ROI coding and WZ coding has efficiently used the limited bandwidth and provide better output quality especially in the interesting area in frame.

References:

- [1] J. Shapiro, "Embedded image coding using zerotrees of wavelet coefficients," *IEEE Trans. Signal Processing*, vol. 41, pp. 3445-3462, 1993.
- [2] J.-R. Ohm, "Advances in scalable video coding," *Proc. of the IEEE*, 93 (1), pp. 42-55, 2005.
- [3] G. Heising, D. Marpe, H.L. Cycon, A.P. Petukhov, "Wavelet-based very low bit-rate video coding using image warping and overlapped block motion compensation," *IEEE Proc.: Vision, Image and Signal Processing*, 148 (2), pp. 93-102, 2001.
- [4] D. Marpe, H.L. Cycon, "Very low bit-rate video coding using wavelet-based techniques," *IEEE Trans. on Circuits and Systems for Video Technology*, 9 (1), pp. 85-94, 1999.
- [5] J. Katto, J. Ohki, S. Nogaki, M. Ohta, "Wavelet codec with overlapped motion compensation for very low bit-rate environment," *IEEE Transactions on Circuits and Systems for Video Technology*, 4 (3), pp. 328-338, 1994.
- [6] A.S. Lewis, G. Knowles, "Video compression using 3D wavelet transforms," *Electronics Letters*, 26 (6), pp. 396-398, 1990.
- [7] H. Eeckhaut, D. Stroobandt, H. Devos, M. Christiaens, "Improving the hardware friendliness of a wavelet based scalable video codec," *WSEAS Transactions on Systems*, 4 (5), pp. 625-634, 2005.
- [8] D. Nister and C. Christopoulos, "Lossless region of interest coding," *IEEE Signal Processing*, vol. 78, pp. 1-17, 1999.
- [9] M. Tun, K.K. Loo, J. Cosmas, "Resilient performance of dirac video codec over packet-erasure channel," *IEEE Trans. on Broadcasting*, 53 (3), pp. 649-659, 2007.
- [10] H. Man, F. Kossentini, M.J.T. Smith, "A family of efficient and channel error resilient wavelet/subband image coders" *IEEE Trans. on*

- Circuits and Systems for Video Technology, 9 (1), pp. 95-108, 1999.
- [11] N.V. Boulgouris, N. Thomos, M.G. Strintzis, "Transmission of Images over Noisy Channels Using Error-Resilient Wavelet Coding and Forward Error Correction," IEEE Trans. on Circuits and Systems for Video Technology, 13 (12), pp. 1170-1181, 2003.
 - [12] J. Liang, R. Talluri, "Tools for robust image and video coding in JPEG2000 and MPEG4 standards," Proc. of SPIE - The International Society for Optical Engineering, 3653 (I), pp. 40-51, 1999.
 - [13] S. Cho, W.A. Pearlman, "Error resilience and recovery in streaming of embedded video," Signal Processing, 82 (11), pp. 1545-1558. Cited 4 times, 2002.
 - [14] Y.Y. Chung, W.K. J. Chin, X. Chen, D.Y. Shi, E. hoi, F. Chen, "Content-based video retrieval system using wavelet transform," WSEAS Transactions on Circuits and Systems, 6 (2), pp. 259-265, 2007.
 - [15] I. M. Stephanakis, G.C. Anastassopoulos, "Object oriented wavelet sub-band coding of medical images with differentiated quality representation per medical object", WSEAS Trans. on Information Science and Applications, 3 (11), pp. 2177-2183, 2006.
 - [16] B. Foo, Y. Andreopoulos, M. Van Der Schaar, "Analytical rate-distortion-complexity modeling of wavelet-based video coders," IEEE Trans. on Signal Processing, 56 (2), pp. 797-815, 2008.
 - [17] Y.-H. Yu, C.-P. Ho, C.-J. Tsai, "Multiple adaptations and content-adaptive FEC using parameterized RD model for embedded wavelet video," EURASIP Journal on Advances in Signal Processing, 2007, art. no. 70914, 2007.
 - [18] N. Ramzan, S. Wan, E. Izquierdo, "Joint source-channel coding for wavelet-based scalable video transmission using an adaptive turbo code," EURASIP Journal on Image and Video Processing, 2007, art. no. 47517, 2007.
 - [19] G. Xing, J. Li, S. Li, Y.-Q. Zhang, "Arbitrarily shaped video-object coding by wavelet," IEEE Trans. on Circuits and Systems for Video Technology, 11 (10), pp. 1135-1139, 2001.
 - [20] G. Minami, Z. Xiong, A. Wang, S. Mehrotra, "3-D wavelet coding of video with arbitrary regions of support," IEEE Trans. on Circuits and Systems for Video Technology, 11 (9), pp. 1063-1068, 2005.
 - [21] S.-C. Han, J.W. Woods, "Adaptive coding of moving objects for very low bit rates," IEEE Journal on Selected Areas in Communications, 16 (1), pp. 56-70, 1998.
 - [22] D. Nister and C. Christopoulos, "Lossless region of interest coding," IEEE Signal Processing, vol. 78, pp. 1-17, 1999.
 - [23] C. Christopoulos, J. Askeloöf and M. Larsson, "Efficient methods for encoding regions of interest in the upcoming JPEG2000 still image coding standard," IEEE Signal Processing Letters, vol. 7, pp. 247-249, 2000.
 - [24] E. Atsumi and N. Farvardin, "Lossy/lossless region-of-interest image coding based on set partitioning in hierarchical trees," IEEE Proc. Int. Conf. ICIP, pp. 87-91, 1998.
 - [25] D. Slepian and J. K. Wolf, "Noiseless coding of correlated information sources," IEEE Trans. Information Theory, vol. IT-19, pp. 471-480, 1973.
 - [26] A.D. Wyner and J. Ziv, "Rate-distortion function for source coding with side information at the decoder" IEEE Trans. on Information Theory, vol. IT-22, pp. 1-10, 1976.
 - [27] B. Girod, A. M. Aaron, S. Rane and D. Rebollo-Monedero, "Distributed video coding," Proc. of IEEE, vol. 93, pp. 71-83, 2005.
 - [28] S. Rane, A. Aaron, and B. Girod, "Error-resilient video transmission using multiple embedded Wyner-Ziv descriptions," ICIP 2005, pp. 666-669, 2005.
 - [29] S. Rane, P. Baccichet, and B. Girod, "Modeling and optimization of a systematic lossy error protection system based on H.264/AVC redundant slices." 25th PCS PROC., 2006.
 - [30] S. Rane, and B. Girod, "Systematic lossy error protection of video based on H.264/AVC redundant slices." Proc. SPIE, 2006.
 - [31] P. Baccichet, S. Rane, and B. Girod, "Systematic lossy error protection based on H.264/AVC redundant slices and flexible macroblock ordering," Journal of Zhejiang University: Science, vol. 7, no. 5, pp. 900-909, 2006.
 - [32] D.N. Rowitch, L.B. Milstein, "On the performance of hybrid FEC/ARQ systems using rate compatible punctured turbo (RCPT) codes," IEEE Trans. on Commun., vol.48, no. 6, pp.948-959, 2000.